XM-1, the high resolution soft x-ray microscope

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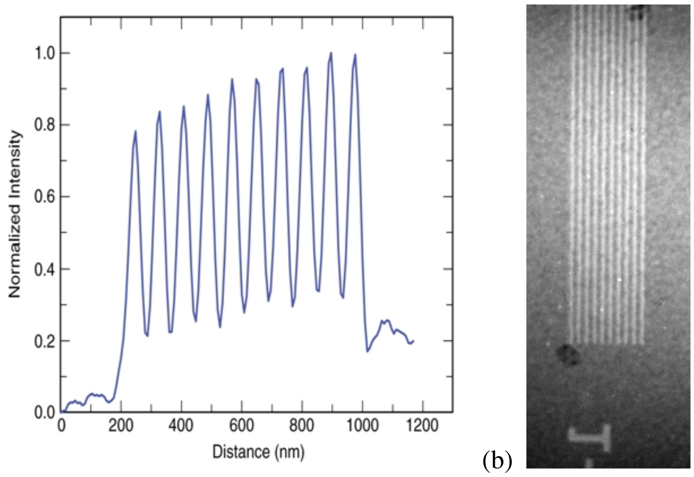
INTRODUCTION

XM-1 is a soft x-ray, high resolution, full-field transmission microscope, built and operated by the Center for X-ray Optics (CXRO) at the Lawrence Berkeley National Laboratory[1]. XM-1 is modeled after a conventional microscope. The x-ray source comes from an ALS bending magnet port on beamline 6.1.2. The x-ray beam is reflected off a glancing-incidence mirror to filter out higher photon energies, yielding an operating range of 250 eV – 900 eV. The x-rays are collected by a 9-mm-diameter fresnel condenser zone plate (CZP) which projects them through a pinhole onto the sample. The radiation that passes through the sample is then imaged by a 25-nm-outer-zone-width micro zone plate (MZP) onto a soft x-ray CCD that records the image. The digital image is then saved on our main computer. Both the CZP and the MZP are fabricated with the Nanowriter electron beam lithography tool in the Nanofabrication Laboratory at CXRO[2].

XM-1 has about a 10 µm field of view and can acquire hundreds to thousands of images per day. Samples can be imaged up to 10 µm thick and may be in an aqueous environment. Exposures are generally a few seconds, which can be reduced by the use of thicker MZPs. Currently there is a trade-off between higher resolution and shorter exposures. Operation of the microscope is controlled by a computer for ease of use. The images obtained with XM-1 are available for viewing almost immediately via the Internet. Using a second computer set up next to the control computer, one can view previously saved images concurrently with ongoing imaging.

Spatial Resolution

We have used several test patterns comprised of small features to explore the imaging capabilities of XM-1. These tests have revealed that the spatial resolution is about 25 nm[3]. Figure 2 shows an x-ray image of 15 nm lines with 60 nm period and the corresponding graph of the intensity modulation.



(a) (b)

Figure 2. Line width of 15 nm with 1:3 duty cycle from a test pattern. (a) Normalized intensity plot of a line-out across pattern. (b) X-ray image of the pattern.

MAGNETIC IMAGING

For over a year, we have been imaging magnetic materials at XM-1. X-ray magnetic circular dichroism (X-MCD) serves as the contrast mechanism when imaged with circularly polarized x-rays (see figure 4). We use elliptically polarized, off-axis, bend-magnet radiation to illuminate the sample. X-MCD is inherently an element-specific probe, which allows imaging a single element in a multicomponent system. X-MCD provides such high contrast that we have shown imaging of element-specific magnetization down to 3 nm thickness. Since this is a photon-based imaging technique, we can apply magnetic fields during imaging without affecting the resolution. We have been applying up to 2000 Oe but plan to increase this further in the next few months. Since X-MCD is sensitive to the magnetization along the photon propagation direction, we can image either in-plane or out-of-plane magnetization by tilting the sample holder.

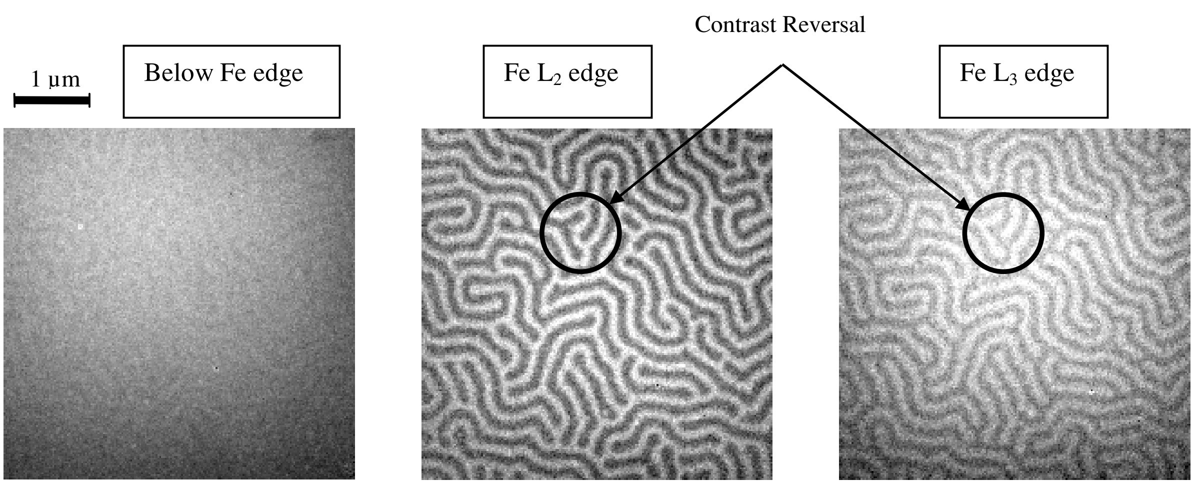


Figure 4. Images of a multilayered 75x(0.4nmGd/0.4nmFe) system. The observed change in contrast between the Fe L_3 and L_2 edges originates in the opposite spin-orbit coupling in the respective $2p_{3/2}$ and $2p_{1/2}$ inneratomic levels and serves as an unambiguous proof of the magnetic character of the domains observed.

FUTURE WORK

We are prepared for testing zone plates of smaller outer zone width to continually improve the resolution limit of XM-1. We expect to use test patterns with smaller features to explore the resolution limit and imaging capabilities of XM-1. We also await higher aspect ratio zone plates for better efficiency and faster imaging.

We are planning to replace our M1 mirror to extend our operating range to 1.2 keV or further while maintaining high throughput at our most commonly used energies.

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